STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
Pullman, Washington

IMPERIAL MYCOLOGICAL INSTITUTE
11 NOV. 1935

The Division of Horticulture

Progress Report of Fertilizer Studies With Jonathan Apples Upon Ephrata Fine Sandy Loam

by

F. L. Overley and E. L. Overholser

Bulletin No. 319

July, 1935

All bulletins of this Station are sent free to citizens of the State on application to the Director

BOARD OF REGENTS

B. A. Perham, President.....Yakima, Wash.
C. W. Orton.....Sumner, Wash.
A. W. Davis.....Spokane, Wash.
W. A. Ritz.....Walla Walla, Wash.
S. A. Kimbrough.....Spokane, Wash.
E. O. Holland.....(President of the College, Secretary, ex-officio)

EXPERIMENT STATION STAFF

E. O. Holland, Ph.D., President
Wm. C. Kruegel, B.A., Treasurer

Edward C. Johnson, M.A., Director
E. V. Ellington, B.S., Vice Director

Agricultural Engineering

L. J. Smith, M.E., Agricultural Engineer in Charge.
H. L. Garver, E.E., Investigator, Farm Electricity.[1]
P. C. McGrew, B.S., Agricultural Engineer, U.S.D.A.[2]

Agronomy

E. G. Schafer, M.S., Agronomist in Charge.
E. F. Gaines, D.Sc., Cerealist.[2]
R. M. Weihing, Ph.D., Asst. in Farm Crops.
S. C. Vandecaveye, Ph.D., Soil Biologist.
L. C. Wheeting, Ph.D., Associate in Soils.
G. O. Baker, M.S., Assistant in Soils.
O. E. Barbee, M.S., Assistant in Farm Crops.
Glenn M. Horner, M.S., Assistant in Soils.
Clarence Seely, M.S., Asst. in Agronomy.
Orville A. Vogel, M.S., Agent, U. S. D. A.[2]
H. P. Singleton, M.S., Associate in Agronomy, Irrigation Branch Station, Prosser.
Carl A. Larson, Ph.D., Specialist in Irrigation Investigations, Irrigation Branch Station, Prosser.[2]
W. A. Rockie, B.S., Scientist in Soil Erosion, U. S. D. A.[3]

Animal Husbandry

Howard Hackedorn, B.S., Animal Husbandman in Charge.
Jerry Sotola, M.S., Asst. Animal Husbandman.
R. E. McCall, M.S., Assistant in Animal Husbandry.

Chemistry

J. L. St. John, Ph.D., Chemist in Charge.
Otto Johnson, M.S., Assistant Chemist.
Kermit Groves, Ph.D., Assistant Chemist.

Dairy Husbandry

E. V. Ellington, B.S., Dairy Husbandman in Charge.
H. A. Bendixen, M.S., Associate Dairy Husbandman.
N. S. Golding, Ph.D., Associate Dairy Husbandman.
J. C. Knott, M.S., Assistant Dairy Husbandman.
C. C. Prouty, M.S., Associate Dairy Bacteriologist.
R. E. Hodgson, M.S., Assistant Dairy Husbandman, Western Washington Experiment Station, Puyallup.[2]
Harvey Murer, B.S., Research Dairy Chemist.

Entomology & Zoology

R. L. Webster, Ph.D., Entomologist in Charge.
James Marshall, M.S., Assistant Entomologist, Wenatchee.
Arthur J. Hanson, M.S., Assistant Entomologist, and Entomologist, Western Washington Experiment Station, Puyallup.

Farm Management & Agricultural Economics

Ben H. Pubols, M.S., Associate Agricultural Economist, Acting in Charge.
E. F. Dummeier, Ph.D., Agric. Economist.
R. B. Heflebower, Ph.D., Associate Economist.
Chester C. Hampson, M.A., Associate Agricultural Economist.
Alden E. Orr, M.S., Asst. in Farm Management.
Howard W. Beers, Ph.D., Assistant Rural Sociologist.

Home Economics

Florence Harrison, A.M., Home Economist in Charge.
Evelyn H. Roberts, M.S., Research Specialist in Home Economics.
Enid Sater, A.B., M.S., Research Specialist in Home Economics.

Horticulture

E. L. Overholser, Ph.D., Horticulturist in Charge.
O. M. Morris, M.S., Horticulturist.
F. L. Overley, M.S., Associate in Horticulture, Wenatchee.
C. L. Vincent, M.S., Asst. Horticulturist.
C. D. Schwartze, Ph.D., Asst. Horticulturist.
W. J. Clore, B.S., Research Assistant.

Plant Pathology

F. D. Heald, Ph.D., Plant Pathologist in Charge.
L. K. Jones, Ph.D., Assoc. Plant Pathologist.
George W. Fischer, Ph.D., Asst. in Plant Pathology.
C. S. Holton, Ph.D., Agent, U. S. D. A.[2]

Poultry Husbandry

John S. Carver, B.S., Poultry Husbandman in Charge.
Victor Heiman, Ph.D., Assistant in Poultry Husbandry.

Veterinary Science

J. W. Kalkus, D.V.S., Veterinarian in Charge, Western Wash. Exp. Station, Puyallup.
C. E. Sawyer, D.V.S., Research Veterinarian, Western Wash. Exp. Station, Puyallup.

Branch Stations

Clarence Seely, M.S., Acting Superintendent, Adams Branch Station, Lind.
H. P. Singleton, M.S., Superintendent, Irrigation Branch Station, Prosser.
D. J. Crowley, B.S., Specialist in Cranberry Investigations, Cranberry Investigations Laboratory, Long Beach.

Pacific Northwest Soil Erosion Station[2]

W. A. Rockie, B.S., Superintendent.[3]
C. E. Deardorff, M.S., Acting Superintendent.
P. C. McGrew, B.S., Agricultural Engineer.
Arthur J. Johnson, Agent.[4]

---

[1] In cooperation with the State Committee on the Relation of Electricity to Agriculture.
[2] In cooperation with the United States Department of Agriculture.
[3] Regional Director, Pacific Northwest Soil Erosion Control Project.
[4] On leave.

TABLE OF CONTENTS

1. Introduction 5

2. Partial Review of Previous Work 5

3. Objects of the Experiment 9

4. Plot Location, Soil, Orchard Layout and Procedure 9

5. Experimental Data 11

I. Tree Response 11

(a) Length of terminal growth of trees 11

(b) Diameter of terminal growth of trees 13

(1a) Correlation of length with diameter of terminal growth 13

(c) Tree trunk circumference 14

(d) Fruit bud winter killing 15

II. Fruit Response 16

(a) Set of fruit 16

(b) Alternate bearing 18

(c) Thinnings 18

(d) Weight of harvested fruit per tree 20

(e) Harvested boxes per tree 21

(f) Size of fruit 23

(g) Color of fruit 24

(h) Grade of fruit 26

(i) Jonathan breakdown 27

6. Discussion 29

7. Literature Cited 33

Progress Report of Fertilizer Studies with Jonathan Apples Upon Ephrata Fine Sandy Loam

F. L. Overley and E. L. Overholser

INTRODUCTION

The proper application of fertilizers to soil for fruit trees is one of the major problems in the fruit investigations now being studied by the Agricultural Experiment Station of the State College of Washington.

Types of soil may vary greatly in their productiveness, depending upon mode of formation, physical condition, chemical composition and depth, biological activities and the climatic influences. These factors, together with variations in orchard management operations have an important bearing upon the results that are obtained from orchard experiments with fertilizers.

Furthermore, the many variations in orchard management practices may influence the growth and productivity of trees and the grade and condition of the fruit more than the fertilizers applied, especially since the response of apple trees to fertilizers usually is not particularly marked. It is not feasible to measure accurately the value of any orchard fertilizer treatment except with carefully controlled experiments. For example, tree growth, size, per cent red color, and keeping qualities of fruit produced are profoundly affected by the factors as follows: (1) the amount and method of application of irrigation water; (2) the kind and stand of cover crop; (3) the methods of cultivation; (4) the varieties; (5) pollination; (6) set of fruit; (7) the condition and number of leaves per apple; (8) the age and spacing of trees; (9) the type and severity of pruning practiced; (10) the spray program with its relation to fruit bud and leaf injury and control of insects and diseases; (11) injury from low temperature to fruit buds and tree roots; (12) time of harvest, and other factors.

Partial Review of Previous Work

The work of investigators in the United States with few exceptions has indicated definitely that there is no appreciable beneficial response by apple trees to applications of potassium (Alderman and Crane, 1920; Morris, 1927; Tukey and Anderson, 1929; Cooper and Wiggans, 1931; Harlan and Collison, 1933). Cooper (1928) reported that upon the basis

of increased vegetative growth, number of fruit spurs, set of fruit, and yields, potassium resulted in no gains and on the average seemed slightly harmful. Furthermore, apparently with few exceptions, there has been little economic benefit to apple trees from applications of phosphorus, except indirectly through its possible effect upon the cover crop, especially legumes (Ballou and Lewis, 1920; Stewart, 1918; Alderman and Crane, 1920; Dorsey and Knowlton, 1926; Cooper, 1928; Fagan, *et al.*, 1933; Harlan and Collison, 1933). Cooper (1928) seemed to find that phosphorus had a beneficial influence upon yield and growth of Ben Davis apple trees in Arkansas, but the responses may have resulted from the beneficial influence upon the cover crop.

Reports by Brooks (1910) and Shaw (1922) in Massachusetts suggest highly beneficial results from all fertilizer treatments, including not only N but also K and P. There was, however, only one check plot and only one plot for each treatment. Shaw himself says that early in the life of the orchard the soil, particularly that of the check plot, which is the lowest in elevation, was too wet. Chandler, (1925) following a visit to that orchard, states that the greater wetness of the check plot was very striking to him. Aeration of the soil, of course, has much to do with the growth, especially of young fruit trees. Chandler believes it is therefore likely—or at least possible—that a part or all of the reduction in growth and yield during the first years of the check plot resulted from the greater wetness and the consequent poor aeration of the soil in the check plot. Furthermore, the yield of the check from 1912 to 1929 increased nearly four times as compared to the yield before 1912, while in a comparable manner, the yields of none of the fertilizer plots were more than doubled.

Shaw (1922) reported that combinations of bone meal with potassium chloride or potassium sulphate increased growth and fruitfulness of the apple trees. According to Chandler, there is not conclusive evidence, however, as to whether this resulted from the N in the raw bone meal, or from the potassium. The differences were not large. There was only one check plot, and the evidence that there was any benefit from the bone meal and potassium was not convincing.

Lyon, Heinicke, and Wilson (1923) in New York found that young Delicious trees on a Dunkirk clay loam failed to respond to phosphorus applications or to nitrogen. In combination with phosphorus, there was a suggestion from the records that these Delicious apple trees may have made a small increase in growth from applications of potassium chloride, but the evidence is not conclusive.

Anthony and Waring (1922) report upon Stewart's work in Pennsylvania and using Student's formula comparing each tree in a treated plot with the nearest tree in the check plot, found the odds were 284 to 1 that phosphorus and potassium sulphate in their plot 6 increased the yield

of York Imperial trees, the odds for the other plots being rather small. According to Chandler (1925) doubt is cast upon the conclusiveness of any of these results, however, when some of the inconsistencies are considered. In plot 6, although with York Imperial trees the odds appeared so large that potassium or phosphorus or both caused a better yield, Staymen apple trees so fertilized yielded less than was yielded by the check trees. With plot 11, in which fertilized Staymen trees showed the greatest yield as compared with the nearest check, York Imperial trees yielded but slightly more than the checks. It is difficult to account for such conflicting variations except that the experimental error was very great—so great that the results either way might be accounted for on the basis of such error. The results by Stewart (1918 and previous) are very uncertain, largely because so many different treatments were tried that it was not possible to have enough distributed plots receiving each treatment.

In the case of the Wertz orchard, as reported by Stewart, potassium sulphate seemed highly beneficial to Jonathan apple trees, but was of no value to York Imperial apple trees. It is indeed questionable that varieties of apples have such sharp differences in their response to potassium. It seems most likely that it was simply the experimental error involved. These and other inconsistencies, together with a large probable error indicate there is no convincing evidence of benefit.

Anthony and Hedrick (1919) while seemingly finding that the addition of 196 lbs. of muriate of potash to the 340 lbs. of phosphoric acid per acre apparently increased the yields, they themselves say their results are so contradictory that no conclusion of practical value can be drawn from the yields. As measured by tree growth, the two phosphorus and potassium plots lead the trees of their adjoining check plots both in size of trunk and in tree volume, but they state it was impossible to conclude that the increases were due to the potash or to the combination of the two elements or to some tree or field variation which does not show. The experimental error is so great that is would certainly be misleading to say there was a conclusive response from P or K.

While nitrogen was the first limiting fertility factor in the growing of apples in Arkansas, Cooper and Wiggans (1931) also apparently found some instances in which phosphorus was of benefit. Likewise, while nitrogen is the element most likely to be deficient, the response of apple trees to applications of nitrogen has been most convincing only upon the lighter sandy, or gravelly soils naturally low in fertility or previously exhausted by relatively long continuous cropping, or where the orchard is planted to a permanent grass sod. This is true not only with young orchards, but also with mature trees, although the latter are more likely to show definite beneficial response than are the former (Alderman and Crane, 1920). With a light soil such "that one would expect trees to respond to fertilizers if they would anywhere," Gourley (1914) found after

five years that the orchard did not show an increase in the yield of the fertilizer plots over those receiving good culture and no fertilizers. Furthermore, neither was there a sufficient increase in the growth of the fertilized trees to warrant the use of fertilizers.

Morris (1927) reported, upon the basis of experiments in the Spokane, Yakima, and Wenatchee districts, that nitrogen-bearing fertilizers when properly used on irrigated orchard soils that had been in clean tillage and where the trees had been making poor growth, were beneficial and caused an increase in growth and in fruit production. He also reported that fertilizers carrying only phosphorus and potash did not increase tree growth or fruit production when applied to his experimental plots in the irrigated orchard soils of eastern Washington. In the irrigated orchards in which a good legume cover crop had been growing for three or more years, he observed no increase in tree growth or fruit production following the application of commercial fertilizers containing either nitrogen, phosphoric acid, or potash, or all of them.

Tukey and Anderson (1929) found no benefit from superphosphate or muriate of potash, either alone or in combination, in any of the apple fertilizer plots. In a young clean-cultivated McIntosh orchard in the Hudson River valley growing upon a soil known as Hoosic sandy loam, an increasing improvement in the non-leguminous cover crop was noted on each plot receiving nitrogen. They pointed out that the "cleaner-cultivated" the orchard, the less the response of the trees to nitrogen fertilizers; while the "less cultivated" the orchard, the greater the response.

Burke, Morris and Harrington (1931) in Montana found that 15-year-old bearing McIntosh trees growing in a soil low in N and P and with usually less than one-third as much K as reported by Morris and Larson (1921) for Washington soils, were benefited by application of these two elements, but not by the application of potassium.

The responses of apple trees seem to be in conformity with the total amounts of three elements generally present in the upper 10 inches of the soils of the United States. Morris and Larson (1921) reported upon the basis of analyses of representative soil types in Chelan County, made by the Soils Section of the Washington Agricultural Experiment Station, that the average number of pounds in the top 10 inches of one acre of soil from the Wenatchee district was as follows: (a) nitrogen, 2170; (b) phosphoric acid, 7040; and (c) potash, 42,900 pounds.

Notwithstanding the investigational data available from fertilizer experiments conducted in other states, the fruit industry has desired careful, fairly complete studies of the responses of apple trees to the application of fertilizers under conditions representative of those in the principal apple districts of the State of Washington. Such experiments of a local character are important and justified, since the results of many

experiments elsewhere, where many soils have been cropped and eroded for from 150 to 200 years, are not applicable to the relatively virgin, irrigated soils of the west.

OBJECTS OF THE EXPERIMENT

In 1927 a project was initiated (1) to study the changes in orchard soils of Washington following various fertilizer applications, and (2) to determine the effect of these applications upon the growth and fruitfulness of the trees and upon the storage and market quality of the fruit. The Soils Section of the Division of Agronomy is responsible for the studies of the soils (Larson 1931 and 1933) and the Division of Horticulture for the tree and fruit responses. The subject matter herewith presented pertains only to tree and fruit responses.

PLOT LOCATION, SOIL, ORCHARD LAYOUT, AND PROCEDURE

The Jonathan fertilizer studies reported herewith concerned the response to nitrogen (N), phosphorus (P), and potassium (K), the elements most generally lacking in the soil. The experiments cover a seven year period.

The experimental plot[2] was started in 1927 in an orchard having as uniform soil conditions as were available in this area. The Jonathan trees planted 26 feet apart on the diagonal were about 18 years old, of a relatively uniform size and of medium vigor at the beginning of the experiment. The orchard is located on the second bench above the Columbia River in the East Wenatchee district. The soil, which is underlaid with water-washed gravel, is fairly uniform in texture and is classified as Ephrata fine sandy loam. (Kocher, 1918).

The pH of the soil is about 6.9. The active constituents of the soil expressed as approximate pounds per 2,000,000 pounds of soil, or that equivalent to a layer approximately seven inches deep over an acre, are as follows: (a) NO_3-nitrogen, 50 (high); (b) NH_3-nitrogen, low; (c) phosphorus as P_2O_5, 350 (high); (d) potassium as K_2O, 600+ (very, very high); and (e) calcium, 7000 (very high). It is seen that the only constituent mentioned which is low is NH_3-nitrogen, the others being "high" to "very, very high."

The ground was nearly level with only sufficient slope to permit adequate irrigation. The irrigation was by the rill system and was uniformly adequate for needs of the trees.

The trees suffered no serious frost or winter injury during the experiment. The variety is self-fertile and the trees are interplanted and

[2] The writers desire to acknowledge the helpful cooperation of Frank Von Osten, owner of the orchard containing the plots.

surrounded with the Delicious and Winter Banana, effective pollenizing varieties.

The soil management of the orchard previous to the initiation of the experiment was as follows: In 1918 about eight pounds of Clark's Special (6-10-4) were applied per tree; during the winter of 1919 and 1920 a "fair spread" of stable manure was applied. In the springs of 1922 and 1926 about six pounds of nitrate of soda were applied per tree; in 1925 and 1926 about six pounds of nitrate of soda per tree were applied in the irrigation ditches about July, just after thinning; and in 1926 about three-fourths of a ton of lime was applied per acre. The orchard had been clean cultivated until 1922, when it was seeded to a cover crop of alfalfa. It has been disced in the spring each year thereafter, with the exception of 1932. The discing, together with the increased competition between the trees and the cover crop has gradually reduced the cover crop stand. The cover crop at present consists of little alfalfa and considerable weeds.

The pruning was conducted by the same man, not only during the experiment but for a number of years previously, so that this operation was as uniform as possible in each of the plots. The pruning would be classed as only moderately heavy and consisted of a combination of cutting back and thinning out. The annual spray program was adequate in each plot to control the insect infestation. Plant diseases have not been a problem. Other orchard practices, such as thinning, were conducted in as nearly a uniform manner as was feasible.

The experimental fertilizers annually applied per tree (since 1927) were approximately equivalent to one pound of actual nitrogen in the form of sulphate of ammonia (5 lbs.), one pound of actual phosphoric acid in the form of superphosphate (6 lbs.), and 2.5 pounds of potash in the form of muriate of potash (5 lbs.).

Each experiment averaged 10 trees to a plot, but only the three center trees were used for records. Each fertilizer treatment consisted of a single plot. There was one buffer row between the plots. The fertilizers of each plot were applied over the intervening ground area to the trunks of the trees of the buffer rows.

The fertilizers were applied annually during the dormant season sometime between December 1 and February 15, on snow over unfrozen ground, the material being broadcast uniformly over the area of each entire plot. This was true in all years except 1927, when the fertilizers were applied in the irrigation ditches in April. All the fertilizers were carefully weighed and each individual fertilizer carrier was applied separately.

EXPERIMENTAL DATA

Observations and data in this bulletin are in the nature of a progress report showing the response of Jonathan on one soil type. It is expected that more complete statements involving other soil types and other varieties will be made available in future years. The data are presented under two sections: (1) tree response, and (2) fruit response.

Tree Response

Length of Terminal Growth of Trees. The terminal length growth of the trees in the different fertilizer plots was taken annually sometime between the dropping of the leaves in the fall and the resumption of growth the following spring. The new season's growth was measured on approximately 20 terminals per tree, around the perimeter of the tree, 6 to 15 feet from the ground. Terminals selected were on large branches or main leaders that had not been pruned for three preceding years or more, thus eliminating growth stimulated by pruning. Shoots growing horizontally, or not exceeding a 45 degree angle in growth from the main tree were selected. By this method, the excessively vegetative upright growth, and those whose growth was restricted by a too drooping position were eliminated. The data pertaining to the annual length of terminal growth as influenced by the kind of fertilizers applied are in Table 1.

Table 1. Average Annual Length of Tree Terminal Growth as Influenced by Fertilizers (Measured in Inches)

Year	N	NP	NK	NPK	PK	C	P	K
1927	9.9	—	—	8.7	6.8	6.9	7.3	5.3
1928	5.1	4.4	4.8	5.1	3.2	4.3	3.9	3.0
1929	9.5	8.7	7.7	8.4	5.6	5.6	4.5	4.6
1930	5.2	5.8	6.8	6.4	3.2	4.5	1.6	2.5
1931	8.2	8.0	7.9	7.4	5.9	5.3	3.9	2.7
1932	9.9	9.9	8.8	9.4	6.3	6.7	4.4	2.7
1933	9.8	7.6	6.3	6.8	4.3	5.1	2.8	1.6
Aver. last 6 years	8.0	7.4	7.1	7.3	4.8	5.3	3.5	2.9

When fertilizers containing nitrogen were applied, either as nitrogen alone or in combination with phosphorus or potassium or both, the average terminal growth made by the Jonathan trees in all such plots was greater than that made by the check trees or trees receiving phosphorus or potassium or both. Nitrogen applied alone tended to result in slightly greater average terminal growth than when applied in combination with the other

two elements. Phosphorus and potassium when applied either alone or together resulted in less terminal growth than that made by the check trees on the basis of the six years, with a tendency for a decreased amount of terminal growth each succeeding year. When phosphorus and potassium were applied in combination without nitrogen the average terminal growth was somewhat greater than when either was applied alone.

Upon the basis of experience in the Jonathan orchards of the Pacific Northwest, it appears that in order to maintain adequate production of fruit of desirable size and color, from six to eight inches of annual terminal growth should be made when measured in the fashion described. Morris (1927) found that heavy crop production of fruit of good size, color, and quality was accompanied or preceded by good growth of trees. His results indicate that neither size, color, quality, nor quantity of the fruit was modified without a corresponding change in the growth and wood development of the trees.

The findings in Table 1 are in general agreement with those of workers elsewhere, when the soil type and soil management are considered. Hedrick (1911) reported that the application of nitrogen to 15-year-old trees growing on a heavy clay loam and with a system of soil management providing clean cultivation until mid-summer and an annual cover crop the remainder of the season, resulted in a somewhat greater annual terminal growth than did trees unfertilized or receiving only phosphorus or both phosphorus and potash. According to Stewart (1918) with 6 to 10-year-old trees growing on sandy loam and stony loam soils in sod orchards, nitrogen was most influential in improving annual terminal growth. Neither phophorus nor lime used alone showed any important influence on terminal growth of apples. Gourley (1919) found that with mature Baldwin trees in an orchard on a light sandy soil, low in phosphorus but well supplied with potassium and with tillage and a leguminous cover crop, the tree growth response to complete fertilizers was not discernible to the eye even after the sixth year when the slightly larger fruit size of the fertilized trees as compared to the check trees was noticeable. The difference in favor of any of the combinations of complete fertilizer used in the different plots was not marked. Bradford (1924) reported that fertilization with sulphate of ammonia or nitrate or soda resulted in increased shoot growth in two orchards in Michigan, but had little effect in a third orchard, indicating that while apple trees may show an increased terminal growth from nitrogen, they do not always do so. Dorsey and Knowlton (1926) found that terminal growth was benefited by applications of nitrogen under some conditions but not by phosphorus or potassium. With Rome, Grimes, York, and Ben Davis, grown in West Virginia, according to these workers, if the terminal growths averaged six to eight inches or more it is doubtful if nitrogen fertilizer is necessary. Anderson (1930) found that even upon the rel-

atively sandy soil of the Hudson Valley in New York that with apple trees only nitrogenous fertilizers produced a noticeable effect upon growth and yield. In a young, clean-cultivated McIntosh orchard in the Hudson Valley growing upon a soil known as Hoosic sandy loam, however, Tukey and Anderson (1929) found no appreciable gain in tree growth even from nitrogen applications.

Diameter of Terminal Growth of Trees. Diameter growth measurements of twigs from which terminal growth was also taken are available for each of three years. In 1931 the diameter at the point just beyond the terminal bud scar separating the growth made in 1931 from that made in 1930 was taken. In 1932 and 1933 it was taken midway between the apical and basal ends of the growth for each season. The data in Table 2 indicate that trees receiving nitrogen either alone or in combination with either phosphorus or potassium or both, produced terminal growth with slightly greater average diameter than did the check trees. With phosphorus alone or potassium alone, or the two elements together, the diameter increase as compared with the check trees tended to be less.

Table 2. The Average Diameter of the Annual Terminal Growth as Influenced by Fertilizers (Measured in Centimeters)

Year	N	NP	NK	NPK	PK	C	P	K
1931[1]	.45	.46	.48	.46	.44	.42	.38	.34
1932[2]	.37	.36	.35	.35	.31	.32	.31	.28
1933[2]	.37	.35	.36	.36	.33	.35	.33	.29
Aver. of '32-'33	.37	.36	.36	.36	.32	.34	.32	.29

[1] Diameter measured just past the enlargement resulting from the union of the two seasons' growth.

[2] Diameter measured midway between the basal and apical portions of the new growth.

Correlation of Length with Diameter of Terminal Growth. The claim has been made in the Pacific Northwest by certain fertilizer salesmen that the addition of certain fertilizers tends to give an adequate terminal growth of a thicker diameter than that on unfertilized trees or on trees not receiving the particular element in the fertilizers applied. Therefore, in 1932 after the trees had received six annual applications of fertilizers, measurements were obtained of the length and diameter of 3000 representative terminal growths of the trees in the plots (see p. 11). The correlation of the length of the annual terminal growth with its diameter was determined. An attempt was also made to ascertain whether there was any possible influence of the fertilizers applied to the relation of the length to the diameter of the terminal growth.

The data showed a definite correlation between the length and the diameter of the annual terminal growth, the longer the terminal growth the greater the diameter. The Jonathan trees receiving potash alone, however, in 1933 made a very inadequate terminal growth averaging 1.6 inches, and with this reduced growth showed no correlation between length and diameter of terminal growth. There was no definite consistent significance that could be attached to the influence of the fertilizers upon the relation of the diameter and length of the terminal growth other than that the longer the terminal growth the greater was the diameter.

Tree Trunk Circumference. The trunk circumference of the trees in the fertilizer plots was measured in centimeters each year by means of a steel tape some time after active growth ceased in the fall and previous to the starting of growth in the spring. The measurement was taken each year at a position marked by a nail on the trunk of the tree from one to two feet from the ground between any enlargement of the crown and the first scaffold limb, the rough bark being rubbed off prior to each measurement.

The data showing the annual increase in centimeters in the trunk circumference over the previous year made by the trees are given in Table 3.

Table 3. The Average Annual Increase in Centimeters in Trunk Circumference per Tree (Jonathan) per Plot Over the Previous Year as Influenced by Fertilizers

Year	N	NP	NK	NPK	PK	C	P	K
1929	2.6	2.4	2.0	2.7	2.3	2.1	2.3	2.0
1930	3.3	3.4	3.5	3.3	2.1	2.4	2.0	1.9
1931	2.8	2.4	3.6	3.1	2.4	2.7	2.5	1.9
1932	2.8	3.5	3.4	2.0	1.6	1.5	2.5	0.9
1933	2.1	3.3	2.7	2.6	1.7	2.0	2.0	1.0
Aver.	2.7	3.0	3.1	2.7	2.0	2.1	2.3	1.6

The data in Table 3 show that the annual increase in centimeters in trunk circumference was somewhat greater where nitrogen was applied than that of the check trees receiving no fertilizers, although the differences were not marked. In view of the fact that the average increase in circumference of the trees of the NPK plot was the same as the trees of the N plot, the addition with nitrogen of either P or K alone or together gave no marked increase in trunk circumference over nitrogen alone, that could be definitely attributed to either P or K. The application of P and K together without N did not benefit trunk circumference. Where P was applied singly there was no consistent significant benefit as measured

by increase in trunk circumference. With the trees receiving K alone, the increase in trunk circumference was less than that of the check trees each of the five years and the difference tended to be increasingly in favor of the check trees with each succeeding year.

Hedrick (1911) in New York State on a fairly heavy soil found that the trunk diameter of the trees receiving fertilizers showed no difference as compared to unfertilized trees, outside the range of variation in the several plots. Collison and Harlan (1923) found that with well-cared-for orchards on the better fruit soils of western New York, there was no consistent increase in trunk diameters of Baldwin, Northern Spy, and Rome Beauty apple trees from 8 to 10 annual applications of phosphorus and nitrogen, or phosphorus and limestone, as compared with unfertilized trees.

Fruit Bud Winter Killing. Fruit bud injury was determined each spring during the time the trees were in full bloom by counting the number of living and dead buds on all spurs on four representative branches on each tree. When the trees were in full bloom no difficulty was experienced in detecting the dead buds. In a few instances the entire cluster of flower buds would be dead but the supporting leaves would be developing normally. Generally, however, at least one or more fruit buds in a cluster would have escaped winter injury and be in bloom. The data showing the percentage of winter killing of fruit buds on the Jonathan trees receiving the different fertilizer applications are shown in Table 4.

Table 4. The Average Per Cent per Tree of Jonathan Fruit Bud Injury from Low Temperature as Related to the Fertilizers Applied

Year	N	NP	NK	NPK	PK	C	P	K
1929	0.2	1.1	1.1	0.5	0.6	0.2	0.6	0.5
1930	3.0	0.8	2.6	1.6	2.0	1.9	3.4	1.3
1931	2.6	2.6	4.2	3.4	3.4	3.5	2.9	4.1
1932	2.4	1.7	3.3	2.0	2.7	5.0	3.7	5.2
1933	1.2	1.1	0.9	1.1	1.1	0.6	1.3	2.2
Aver.	1.9	1.5	2.4	1.7	2.0	2.2	2.4	2.7

In no case has the fruit bud injury from low winter temperatures been severe. The data indicate that there has been no significant direct influence upon winter killing of fruit buds from the application of fertilizers. It is likely, however, that trees in better vigor that mature properly in the fall, may withstand low temperatures somewhat more satisfactorily than will weak trees. The trees receiving P alone or K alone were less vig-

orous, as measured by terminal growth than were the trees of the other plots, especially those receiving N alone or in combination with phosphorus.

Fruit Response

Set of Fruit. Table 5 gives the results of four years' application of fertilizers upon the per cent of fruit set and the total number of fruits set by the trees. The trees had received the experimental applications of the fertilizers indicated since 1926, but the records given here are only for the four years after 1929, in order that the measurable effects of the fertilizers would have prevailed.

With some of the trees in the various fertilizer plots there appeared to be a tendency toward alternate bearing. This tendency, however, may result from some cause other than the fertilizer treatment, such as a variation in the time of fruit thinning. Therefore, the annual per cent of spurs blooming was determined by counting all the spurs on several representative branches of each tree at the time of blooming and thus ascertaining the approximate per cent of spurs each year that were blooming. In each plot an average of approximately 750 spurs thus was annually examined. The relation of the different fertilizer applications to the per cent of spurs per tree that annually bloomed, therefore, also is shown in Table 5.

Nitrogen alone or in combination with phosphorus or potassium caused an increased percentage set of fruit in comparison with the unfertilized plots and the plots to which phosphorus or potassium alone or together were applied. Over the period of four years the trees in the NP plot gave the highest per cent set of fruit, although the average number of apples set including both thinnings and harvested fruit was essentially the same as in the N and NK plots.

Bradford (1924) reported that applications of nitrogen increased the per cent set of fruit upon both old and new spurs of Ben Davis and Oldenburg trees as compared with unfertilized trees. McCue and Lagasse (1925) reporting the response of Jonathan trees in Delaware to the application of fertilizers for 15 years stated that nitrogen increased the percentage of bloom that set. Tukey and Anderson (1929) reported that under Hudson River Valley conditions in New York on light sandy soils, the outstanding effect of fertilizers was the increased set of fruit when nitrogen was applied, and the subsequent objectionable effect of heavy cropping upon the trees and upon future crops.

The trees in the P and K plots were the lowest in per cent set and also in actual total number of fruits set. The trees in the plot receiving a combination of PK gave a per cent set approximately equal to the unfertilized trees. The data in Table 5 may seem to show a slight increase

Table 5. Average Per Cent of Fruit Set; the Average Per Cent of Spurs Blooming; and Total Number of Fruits Set; After June Drop

Plot	Year	Per cent of spurs blooming	Actual per cent fruit set after June drop from buds blooming	Total number fruits set
N	1930	92.9	9.6	4873
	1931	77.5	12.1	4149
	1932	49.9	17.1	3450
	1933	85.2	11.4	3820
Average		76.4	12.3	4073
NP	1930	80.1	12.2	4691
	1931	71.4	14.0	3738
	1932	51.6	17.0	4024
	1933	93.3	12.3	3924
Average		74.1	13.9	4094
NK	1930	79.4	9.9	4444
	1931	68.4	11.7	3431
	1932	64.6	16.0	4051
	1933	84.2	13.9	4364
Average		74.2	12.9	4075
NPK	1930	71.8	11.7	4152
	1931	71.5	10.2	3157
	1932	68.6	13.3	4201
	1933	75.6	14.7	3575
Average		71.9	12.5	3771
PK	1930	75.4	9.0	3191
	1931	64.4	11.6	2759
	1932	65.7	9.5	2741
	1933	77.2	8.5	1865
Average		70.7	9.8	2639
C	1930	85.0	8.0	3406
	1931	71.5	9.7	2623
	1932	47.0	11.2	1898
	1933	93.0	9.5	3132
Average		74.1	9.6	2765
P	1930	69.7	6.6	1866
	1931	46.4	6.1	1878
	1932	47.7	4.4	1086
	1933	83.3	4.1	826
Average		61.8	5.3	1414
K	1930	88.4	7.5	2511
	1931	72.1	7.8	2258
	1932	39.5	4.9	1226
	1933	80.6	3.5	1059
Average		70.2	5.9	1765

in per cent set from NP and possibly NK as compared with N alone. It appears, however, the nitrogen was the element involved in the per cent increase in set because the per cent increase in set, as compared with the check, for the trees of the NPK plot was essentially the same as for the trees of the N plot; furthermore, the total number of fruits set by the trees of the NPK plot averages less than those of the N plot. The decreasing set of fruit from year to year by the trees in the P and K plots may result from a reduced vigor of terminal growth, which annually is becoming more marked, possibly due to an accumulative direct or indirect effect of the fertilizer treatment.

Alternate Bearing. Tukey and Anderson (1929) observed in two orchards that nitrogen applications resulted in a greater set of fruit in the "on" or bearing year and a corresponding decrease in the "off" year. Studies by Heinicke (1930) indicated that the behavior of apple trees with respect to their habit of bearing in alternate years can not easily be influenced by changes in fertilization or by pruning. Certain workers, however, have indicated that the tendency to alternate bearing can be definitely modified or controlled by proper fertilizer applications. Bradford (1924) found that younger branches of Ben Davis and Oldenburg trees fertilized with nitrogen showed a strong tendency toward the production of annual crops. With unfertilized trees of these varieties the young branches were strongly biennial in their bearing habits. Harlan and Collison (1933) found that alternate year application of nitrogen during the "on" year did not result in increased yield of fruit. It seems doubtful under western irrigation conditions, with thinning bringing about an adequate leaf-fruit ratio (Magness, Overley and Luce, 1931) and with the other desirable orchard practices followed, whether fertilizers applied consistently influence possible alternate bearing tendencies. Table 6 gives the per cent of spurs per tree each year that bloomed in the different fertilizer plots.

The data in Table 6 giving the per cent of spurs per tree that bloom each year do not accurately indicate a tendency of the trees toward alternate bearing. From a study of this table, together with the data in Table 5, however, it appeared that the tendency with all the fertilized trees, as well as with the non-fertilized trees, was for above average blooming of spurs for the plot for two to three successive years with minor fluctuations, and then an appreciable reduction in the per cent of spurs blooming for a year or two, with again two or three years above average. The fertilizers applied did not appear to definitely and consistently influence or correct such alternate bearing tendencies.

Thinnings. Growers are interested primarily in the harvested crop, which alone, however, can not be taken as a measure of yield response to fertilizers. The crop on each tree may be made nearly uniform

Table 6. The Per Cent of Spurs per Tree That Bloom Each Year

Fertilizers applied	Tree No.	1928	1929	1930	1931	1932	1933	Grand average
	1	27.4	61.6	90.5	87.9	31.0	96.2	
N	2	64.3	29.4	92.0	71.7	64.6	71.6	66.0
	3	76.1	13.2	96.2	72.8	54.0	87.9	
Annual average		55.9	34.7	92.9	77.5	49.9	85.2	
	1	63.6	43.9	80.0	77.5	45.4	95.0	
NP	2	46.5	21.6	93.9	58.3	63.1	88.7	63.8
	3	38.6	44.3	66.4	78.4	46.3	96.6	
Annual average		49.6	36.6	80.1	71.4	51.6	93.3	
	1	44.3	14.0	91.8	63.0	69.6	77.3	
NK	2	47.1	54.4	89.8	66.5	77.3	90.0	64.2
	3	51.5	54.1	56.6	75.6	46.8	85.3	
Annual average		47.6	40.8	79.4	68.4	64.6	84.2	
	1	50.0	51.8	49.0	76.9	73.1	82.7	
NPK	2	51.2	31.9	83.5	65.2	58.4	65.7	63.5
	3	48.0	48.1	83.0	72.4	74.3	78.5	
Annual average		49.7	43.9	71.8	71.5	68.6	75.6	
	1	78.1	36.0	91.2	60.7	87.0	64.0	
PK	2	56.2	33.3	85.1	61.6	65.2	78.6	64.5
	3	53.8	55.4	49.8	70.8	44.9	89.0	
Annual average		62.7	41.6	75.4	64.4	65.7	77.2	
	1	63.9	33.3	98.0	63.7	53.7	87.2	
Check	2	—	31.0	80.9	75.3	61.0	95.0	67.0
	3	—	51.7	76.1	75.3	26.4	96.8	
Annual average			38.7	85.0	71.5	47.0	93.0	
	1	45.5	63.0	46.8	7.9	5.5	98.5	
P	2	74.5	26.9	95.2	60.5	78.3	67.5	58.0
	3	39.4	54.1	67.0	70.7	59.2	84.0	
Annual average		53.1	48.0	69.7	46.4	47.7	83.3	
	1	56.3	57.5	97.1	61.9	69.5	45.6	
K	2	62.1	64.6	84.4	74.0	28.7	97.9	66.9
	3	43.0	78.9	83.7	80.5	20.2	98.3	
Annual average		53.8	67.0	88.4	72.1	39.5	80.6	

by good thinning practices. Hence, trees with a moderate or light set of fruit may at harvest time mature a crop of fruit nearly as heavy as trees with an original heavy set, but with correspondingly heavier thinning. Although fruits thinned from trees in the plots receiving nitrogen alone or in combination with phosphorus and potassium were greater in number than the fruits thinned from trees in plots not receiving nitrogen, to date

as a result of the thinning practiced the actual number of specimens harvested has not shown such marked differences. Table 7 gives the average number of fruits thinned per tree.

Table 7. The Average Number of Fruits Removed by Thinning per Tree per Plot

Year	N	NP	NK	NPK	PK	C	P	K
1930	1409	1534	1363	1226	699	873	215	287
1931	1198	1179	969	750	551	502	208	241
1932	853	1485	1251	1258	434	286	198	82
1933	795	1358	1343	1411	309	920	63	116
Aver. of 4 yrs.	1064	1389	1231	1161	498	645	171	181

The number of young fruits removed at thinning time, in the case of trees receiving nitrogen either alone or in combination with phosphorus or potassium or both has been consistently greater than that removed from the trees in the check plot or from the trees receiving phosphorus or potassium alone or together. The data on the average show that there were larger numbers of fruits thinned from the trees of the NP, NK, and NPK plots than from the trees of the N plots. Too much weight, however, cannot be attached to such differences as seem to exist between the trees of plots receiving N alone and N with either P or K or both added. The differences are not nearly so marked as those between the plots without nitrogen and the plots receiving nitrogen. The application of phosphorus and potassium together without nitrogen has not resulted in an increased number of thinned fruits in comparison with the check trees. The application of either phosphorus alone or potassium alone has resulted in a greatly decreased number of annually thinned fruits as compared with check trees, and this tendency seems to be accentuated each succeeding year.

Weight of Harvested Fruit per Tree. The weight of fruit harvested, together with the size, should be an accurate index of the yield, since apples in the Northwest are packed in boxes with the number of specimens therein stamped on the box together with the minimum net weight.

Since weight of fruit produced per tree is a measure of yield, direct comparisons are made between plots. The total yields of harvested fruit are in Table 8. This table includes the yields of fruit from each of the fertilizer plots compared with the check or non-fertilized plot for each series.

Table 8. The Average Weight in Pounds of the Harvested Fruit per Tree

Year	N	NP	NK	NPK	PK	C	P	K
1928	420.0	403.7	301.7	388.3	388.0	492.0	358.0	346.0
1929	629.3	794.3	755.8	661.3	678.8	497.7	492.8	663.5
1930	916.5	881.8	914.2	850.2	592.3	701.0	413.3	514.0
1931	832.8	733.9	724.3	597.8	570.8	550.0	384.8	441.7
1932	653.7	737.5	846.0	790.0	569.0	446.8	240.3	268.3
1933	828.0	764.6	847.0	555.8	420.3	576.5	194.0	234.5
Aver. 6 years	713.4	719.3	733.3	640.6	536.5	544.0	347.2	411.3
Gain or loss in lbs. over check	169.4	175.3	189.3	96.6	—7.5	—	—196.8	—132.7
Per cent increase or decrease compared with check	31.1	32.2	34.8	17.8	—1.4	—	—36.2	—24.4

The results show that the increase in average annual production over the check trees resulting from the fertilizers was in the four plots of trees receiving nitrogen alone and in combination.

The trees receiving NK showed an increase in yield of about four per cent more and those receiving NP about one per cent more than did the trees receiving N alone. It is difficult to be certain, however, that this resulted from the K or the P addition to the N because with NPK or where both P and K were added to N the increase in yield was less than with the application of N only. It would seem that if in the case of K added to N and in the case of P added to N there had actually resulted increases in yields from the additional elements that the increase where both had been added to N should be still greater. The reverse, however, is true. The PK plot yield was about comparable to the check. The trees in the P plot were the poorest in the series in yield and the yield from the trees of the K plot averaged 24.4 per cent less than that of the check trees.

Harvested Boxes per Tree. Total yield per tree is profoundly influenced by climate, cultural practices, size of tree, tree vigor, soil types, and soil moisture. Nevertheless, where nitrogen has been a limiting factor, the addition of nitrogen either alone or in combination with either phosphorus or potassium or both has generally resulted in increased yields. Forty-two pounds is a fair net average weight per packed box of Jon-

athan and is used in these studies as a basis for determining the number of boxes by dividing the total weight by 42 pounds. Six years' data showing the average number of loose boxes of apples harvested per tree from the fertilized Jonathan plots are in Table 9.

Table 9. The Average Number of Harvested Boxes per Tree in the Plots Receiving Different Fertilizers (Ave. of 6 yrs. 1928-1933)

Year	N	NP	NK	NPK	PK	C	P	K
1928	10.5	9.6	7.1	9.2	9.2	11.7	8.5	8.2
1929	15.5	18.9	18.0	15.7	16.2	11.6	11.7	15.8
1930	22.4	21.0	21.6	20.2	14.1	16.7	9.8	12.2
1931	19.8	17.5	17.2	14.2	13.6	13.1	9.2	10.5
1932	16.5	17.6	20.3	18.8	13.5	10.6	5.7	6.4
1933	19.7	18.2	20.1	13.2	10.0	13.7	4.6	5.6
Aver. 6 years	17.4	17.1	17.4	15.2	12.8	12.9	8.3	9.8

Using the harvested boxes per tree as a basis of yield, the nitrogen seemed to be the element responsible for the increased yields. The average decrease of three-tenths of a box for NP as compared to N alone, in view of the variable factors associated with yield, does not appear to be significant, especially since the yield with NK averaged the same as with N alone and where both P and K were applied with N (NPK) the yield was 2.2 boxes less than where N alone was applied.

The average yields of trees on the PK and check plots were about the same and were less than those of the N or N-bearing fertilizer plots. When either P or K was applied alone, however, the number of harvested boxes of fruit per tree averaged less than that of the check or PK plots, even though the lessened number of thinned fruits had a tendency to equalize the number of boxes of fruit matured per tree. Furthermore, during the last five years the yield of the trees being fertilized with either P or K alone seem to be consistently becoming less each succeeding year.

Upon the basis of soil differences and soil management practices the data in Table 8 were in general agreement with work reported elsewhere. Hedrick (1911) in reporting a 15-year experiment with Rome apples grown on a relatively heavy clay loam stated that the fertilizers (N, P, and K) had no marked effects upon the yield of fruit. Stewart (1918) found nitrogen to be most important in improving yield of apples, but the addition of phosphorus or potash to the nitrogen applications sometimes gave larger returns than nitrogen alone. This was not always the case, however, and in three bearing orchards the addition of phosphorus

resulted in no important benefit, and in two of the eight experiments potash apparently had an injurious effect upon yield.

Gourley (1919) reported that mature Baldwin trees receiving complete fertilization failed to respond to their treatment with increased yields of fruit. In some cases they made very slight gains and in others no increase in yield as a result of fertilizers applied. Collison and Harlan (1923) did not find any consistent increase in yield of fruit by varieties of apples growing on the better soils of western New York from applications of various combinations of nitrogen, phosphorus and potassium. McCue and Lagasse (1925) reported Jonathan trees on plots receiving nitrogen either alone or in combination with phosphoric acid or muriate of potash bore the largest and most regular crops. In respect to yield, acid phosphate or muriate of potash, alone or in combination, gave no benefit. Morris (1927) upon the basis of fertilizer studies in eastern Washington reported that the largest quantity of fruit was produced by trees making a strong wood growth, but not the most succulent growth.

Anderson (1932) found with McIntosh and Delicious trees on the sandy soils of the Hudson Valley that the total yield over an 8-year period was increased when nitrogen was applied either singly or in combination. No evidence, however, was found that either phosphorus or potash had materially increased yields. Harlan and Collison (1933) found in western New York, with four varieties of apples, no evidence that a complete fertilizer containing nitrogen, phosphorus, and potash increased yields above those obtained from the use of nitrogen alone.

Size of Fruit. Size of fruit is influenced by tree load, functioning leaf area available, and moisture relationships in addition to the effect of the fertilizer. It does not, therefore, necessarily follow that fertilizers will result in size increase of fruit if at the same time tree load is increased.

Table 10. The Average Size of Fruits (Number per Box) From the Various Fertilizer Plots as Indicated by the Number of Apples per Box. (Average of 6 Years)

Year	N	NP	NK	NPK	PK	C	P	K
1928	161	140	141	157	171	163	178	179
1929	136	145	145	151	157	143	161	167
1930	155	149	142	144	180	153	176	185
1931	149	147	143	169	164	162	181	190
1932	158	142	138	157	170	153	159	179
1933	153	142	150	161	157	157	165	173
Aver. 6 years	152	144	143	157	167	155	170	179

The average actual sizes of fruit for the last five years in the various plots where fertilizers were annually applied, are given in Table 10.

The data in Table 10 indicate that the use of phosphorus or potassium singly or together resulted in smaller size of individual Jonathan apples than those from the unfertilized plot, notwithstanding the reduced crop borne by these trees. The application of nitrogen either alone or in combination with either P or K has tended to somewhat increase the size of the individual fruits as compared with unfertilized trees. As compared with N alone, the increase in size was somewhat greater in the plots where N was combined with either P or with K but size was somewhat less even than the check when N was combined with both P and K. It would seem, therefore, that the response was primarily from N. Morris (1927) found that the largest size fruits were generally produced in the fertilized plots where the trees were carrying a light crop of fruit and making the largest amount of annual terminal growth; and that the converse of this usually was true. Tukey and Anderson (1929) and Hedrick (1911) found that when the set of fruit as a result of nitrogen applications was very heavy it resulted in small size of individual specimens. When the set of fruit was not unduly increased the size was possibly slightly increased. Anderson (1930) reported an instance with the Yellow Newtown where nitrogenous fertilizers so stimulated the set of fruit that trees receiving nitrogen graded only 18.7 per cent of apples two and one-half inches in diameter, while those receiving no nitrogen graded over 63.6 per cent in this size. With Delicious (1932), however, nitrogen applications tended to increase the size of individual fruit specimens.

Gourley (1914) reported that in New Hampshire the size of apples was increased by the use of fertilizers, especially by the use of excess nitrogen and potash. There was, however, no cash return for the fertilizer used. In the experiments reported by Stewart (1918) fertilization with nitrogen, phosphorus, and potash (although with the latter the average size of fruit may have been increased in three experiments) usually had very little influence upon the average size of the fruit. This was apparently because the total amount of fruit was increased and this tended to decrease the average size of the specimens. Gourley (1919) later reported that the fertilizer combination richest in potash gave the largest apples, but that the difference was not, however, especially outstanding.

Color of Fruit. With normal trees adequately supplied with soil moisture, nitrogen, either alone or in combination, tends to oppose the development of maximum red color, possibly primarily by first delaying maturity attainment of the crop, and second, by giving more shade from increased leaf development. Certain other factors that may lessen intensity and amount of red color development are as follows: unfavorable growing conditions, excessively high summer temperatures, reduced sun-

light through hazy or cloudy weather, crowded condition of trees, insufficient or excessive pruning, inadequate irrigation, excessively vigorous vegetative growth, attacks of leaf-injuring insects, reduced ratio of leaf area per fruit, and insufficient maturity of fruit before harvest.

The color of all Jonathan fruits from each of the trees of the fertilized plots was determined by grading each apple according to the per cent of red color as follows: A=90-100; B=70-90; C=50-70; D=30-50; E=10-30; F=0-10. The average per cent color was then determined by the following method:

$$\frac{95A + 80B + 60C + 40D + 20E + 5F}{\text{Number of fruits}} = \text{Per cent red color.}$$

The sum of all fruits with 90-100 per cent color multiplied by the average 95 plus all fruits with 70-90 per cent color multiplied by the average 80 and so on including F, then dividing the sum by (N) number of fruits, the result is obtained in average per cent red color as in Table 11.

Table 11. The Average Per Cent of Red Color of Fruit From the Different Fertilizer Plots

Year	N	NP	NK	NPK	PK	C	P	K
1928	58.4	63.2	64.8	68.2	70.9	69.5	79.3	70.1
1929	61.0	51.4	53.2	51.6	59.4	72.6	75.9	72.9
1930	51.6	66.3	66.4	66.3	79.9	81.5	90.1	86.0
1931	71.8	76.9	73.5	73.0	85.3	88.8	92.5	93.4
1932	54.7	57.9	63.8	56.7	77.4	77.6	88.7	88.9
1933	67.0	72.0	54.0	66.0	90.0	78.0	95.0	93.0
Aver. 6 years	60.8	64.6	62.6	63.6	77.2	78.0	86.9	84.1

In plots where nitrogen was applied either alone or in combination with P or K, or both, the per cent of red color on the surface of the apples was less than that on the apples from the check trees. Under some conditions, larger size of fruit and increased total tree yield may offset possible lower returns from lessened red color development, due to the application of nitrogen fertilizers. There has been no evidence obtained that the application of either potassium or phosphorus fertilizers improves the red color of apples, except when the addition of these elements might tend to reduce the effect of the nitrogen applied. If only potassium or phosphorus is applied singly or in combination the red color of the apples may be better than when nitrogen is applied, not directly because of the phosphorus and potassium but because of the lack of excess nitrogen.

The average per cents of red color on the apples from the P and K plots were slightly greater than that on the fruit from the check plots. The colors of the former were generally a darker red than that of the latter, but on some of the exposed portions of the trees of the former, the fruit was often of a dull lusterless character with considerable evidence of sunburning. The red color seemed to have been developed by the greater intensity of sunlight resulting from the marked decrease in foliage (Overholser and Overley, 1933) on trees fertilized with P or K alone. Furthermore, such fruit was of so small an average size and the annual yield and terminal growth were so reduced that the production of these trees was very unprofitable. The average color of fruit from the PK plots, without any nitrogen, was essentially the same as that of fruit from the check plots.

The findings in Table 11 are in general agreement with those of other workers. Hedrick (1907) found, even when applied in amounts in excess of the usual recommendations, that acid phosphate and potash did not improve the red color of apples. Gourley (1914) found that the red color of fruit was not increased by any combination of fertilizers he employed. According to Stewart (1918) the red color of apples can not be increased materially by any kind of fertilization, although potash and possibly phosphorus may sometimes assist very slightly. He stated that the distinctly retarding influence of nitrogenous fertilizers and manure on red color development results from delayed maturity. Alderman and Crane (1920) found that phosphorus and potassium had no effect upon the color of apples, but that nitrogen directly inhibited red color development. According to Grubb (1928) on the soils of East Malling, England, which are low in available potassium, and where potassium sulphate applications to apple trees increased the quantity and size of the fruit, no consistent tendency towards more highly colored fruit was observed. In some cases potassium applications resulted in less highly colored fruits, which Grubb believes probably resulted from the denser foliage where potassium was applied. Tukey and Anderson (1929) found that when a very heavy set of apples resulted from the nitrogen applications the fruit was poor in color. Anderson (1932) found that the red color of Delicious was lessened somewhat by application of nitrogen fertilizers but not enough to seriously affect market value. A relatively high degree of color, however, is attained on the sandy soil and with the sunshine of the Hudson Valley. Harlan and Collison (1933) found in New York that excess quantities of nitrogen resulted in a reduction in the red color development.

Grade of Fruit. As shown fertilizers, especially nitrogen, have a significant influence upon the per cent of red overlay color developed upon apples. Since color is such an important factor in establishing the principal grades of the State of Washington, fertilizers may exert a marked influence upon the per cent of fruit falling within each grade. The

influence of fertilizers upon the percentage of the four grades of fruit (based upon 1933 requirements), produced is averaged in Table 12.

Table 12. Summary of Average Per Cent of the Four Grades (Based Upon Color)[1] of Jonathan Apples from the Different Fertilizer Plots (1928-1933 inc.)

Grades	N	NP	NK	NPK	PK	C	P	K
				Per Cent				
Extra fancy	67.4	72.8	69.4	70.1	86.9	91.0	96.9	93.4
Fancy	13.5	13.8	14.5	14.3	8.1	6.0	1.9	4.5
"C"	11.9	9.8	11.6	11.3	4.1	2.6	0.9	1.7
Culls	7.2	3.6	4.5	4.3	0.9	0.4	0.3	0.4

[1] The color requirements for Jonathan during the 1933 season for grades were as follows: (a) extra fancy, 50 per cent ;(b) fancy, 25 per cent; (c) "C" grade, 10 per cent; and (d) culls, 0 to 10 per cent.

The trees in the check and PK plots produced on the average a lower percentage of "C" and cull grade fruit and a higher percentage of "extra fancy" fruit, as determined by color only than were produced by the trees in the other plots receiving nitrogen alone or in combination. The per cent of extra fancy fruit produced by the trees of the P and the K plots was slightly more than produced by the check trees, but the amount was considerably less. Otherwise, the trees of the check plot produced a higher percentage of extra fancy fruit than did the trees of any of the plots. The extra fancy grade fruit produced by trees receiving N alone was slightly less than when applied in combination with P or K or both. The differences, however, were not marked.

Jonathan Breakdown. Large-sized fruit is more subject to Jonathan breakdown than is small-sized fruit (Palmer, 1930). Furthermore, fruit from trees having a large leaf area per fruit is more susceptible than is fruit from trees having a limited leaf area per fruit (Overley and Overholser, 1931). The per cent of Jonathan breakdown after five months' storage at 32° F. for Jonathan fruit from trees having different controlled leaf areas per fruit was as follows: (a) 10 leaves per apple, none; (b) 15 per apple, none; (c) 25 per apple, 28.9 per cent; (d) 40 per apple, 50 per cent. Jonathan apples packing 138 per box or larger are more subject to breakdown than are apples of smaller size. Hence, since the apples from the plots receiving nitrogen alone or in combination averaged in size larger than those from the plots not receiving nitrogen, the former tended to develop breakdown. Thus, insofar as fertilizer applications may increase the size of fruit, and may give a relatively large leaf area per fruit borne, the susceptibility to Jonathan breakdown may be increased. Overholser and Overley (1933) found, as compared to check trees

and trees receiving no nitrogen, that Jonathan apple trees receiving nitrogen alone or in combination had the larger leaf area.

The per cents of breakdown observed in Jonathan apples from the different fertilizer plots for the crops of 1928 to 1932 inclusive are shown in Table 13.

Table 13. The Average Per Cent of Jonathan Breakdown per Plot per Year After Eight Months' Cold Storage at 32° F.

Crop year	N	NP	NK	NPK	PK	C	P	K	Yearly average
1928*	7.3	3.3	0.7	2.5	0.3	3.5	0.6	2.0	2.5
1929	35.7	23.2	31.0	21.9	11.0	28.4	21.9	20.5	24.2
1930	6.0	6.0	5.1	10.6	2.7	1.1	4.5	1.3	4.7
1931	2.1	30.5	8.2	21.2	4.3	4.0	10.3	4.5	10.6
1932	4.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.7
1933	0.0	3.2	0.0	0.0	12.8	0.0	7.5	1.3	3.1
Average	9.3	11.1	7.5	9.4	5.2	6.2	7.5	4.9	

* 6 months cold storage

The data indicate that breakdown varied from season to season regardless of the fertilizer treatment. This is in agreement with Palmer (1930). It is of interest to note that during the season of 1929 all plots showed far more breakdown than was exhibited any of the other seasons. The fruit harvested in 1929 averaged lower in firmness of flesh after three months' storage than was the case during any of the other five years. Gourley and Hopkins (1931) also reported that, under Ohio conditions, the 1929 crop of both Jonathan and Stayman Winesap was severely affected with trouble similar to Jonathan breakdown. During the season of 1932 the per cent of breakdown was very low, averaging less than one per cent.

The results in Table 13 indicate a difference in breakdown of fruit from the trees of the different plots during the same season. The trees within a plot showed considerable variation. These differences, however, are not consistent but vary each season, which would tend to emphasize further that other factors aside from the fertilizer are more directly responsible for the breakdown except as fertilizers affect the size, maturity, and color of fruits, and the leaf-fruit ratio.

In no case during the five years of observation was any breakdown noted on the December 15 examinations of the cold storage fruit. After five and eight months' storage, however, fruit from the nitrogen and nitrogen-bearing fertilizer plots averaged slightly higher in per cent of

breakdown than did fruit from the PK and check plots. This may have resulted from the fact that the PK and check fruits averaged a trifle smaller in size and higher in red color than did the fruit from other plots, even though an effort was made to select samples of the same size (125) and color (extra fancy).

DISCUSSION

The data indicate with the variety and soil type involved and the duration of the experiment considered that the most marked response of apple trees, as measured by annual length and diameter of terminal growth, per cent of spurs that bloom each year, set of fruits, and yield, was from the annual application of nitrogen alone. It is possible that if a more satisfactory stand of alfalfa cover crop had been maintained that this legume would have more completely supplied the nitrogen needs of the trees. There was, however, no significant difference in the stand of alfalfa as influenced by the fertilizers applied to the different plots.

In the case of certain responses as measured the use of the complete fertilizer (NPK) as compared with N alone or in combination with either P or K seemed to have a depressing effect. This seemed true in the case of the following factors: (a) average per cent of spurs blooming, (b) the total number of fruits set, (c) the average number of harvested boxes of fruit per tree, (d) the average weight in pounds of harvested fruit per tree, and (e) the average size of individual apples. In the latter case, the size averaged slightly smaller than that of the apples from the check trees.

The application of P alone or of K alone as measured by the growth and fruiting responses employed seemed to be generally objectionable and undesirable.

For the first three to five years of the experiment, the application of P and K together without N did not give any marked benefit, and did not seem to result in any harm to the growth and fruiting of the trees. During the last two to three years, however, the trees so fertilized have shown an increasing decline in tree vigor. The trees in plots receiving P or K alone and PK after seven years showed a very weak condition with a dying back of terminal growth and light colored, sparse foliage with almost no fruit crop. In fact, these trees were becoming so weak that in order to bring them back into adequate vigor of growth and production, it was necessary during the 1934-1935 dormant season to apply nitrogenous fertilizers to the trees in the form and amount as received by the trees of the other plots. Observations made in June, 1935, show that the trees had greatly benefited, as measured by terminal growth and set of fruit, by the nitrogen application.

RECOMMENDATIONS

Unless a heavy leguminous cover crop growth can be maintained in the orchard, the annual addition of about one-half pound of actual nitrogen per mature apple tree may be justified. On trees lacking in vigor or with varieties where color and early maturity are not factors in obtaining fruit of a profitable grade and where tonnage and size of individual specimens are primarily desired, or in trees growing in light to sandy soil, the actual nitrogen annually applied may be increased to one pound or more per tree. A suitable time to apply this nitrogen is during the dormant season, preferably on a snowfall if the ground is relatively level and not frozen.

SUMMARY

1. Measurements were made of certain responses of mature Jonathan apple trees, growing upon Ephrata fine sandy loam in the Wenatchee district, to seven annual winter applications of single elements and of the various combinations per tree amounting to five pounds of sulphate of ammonia, six pounds of superphosphate, and five pounds of muriate of potash.

2. Jonathan apple trees receiving nitrogen alone or in combination with phosphorus or potassium or both made a greater average annual terminal growth than did the trees of the check plots or trees receiving phosphorus or potash or both. The trees receiving nitrogen alone made a slightly greater terminal growth than those receiving nitrogen in combination with the other two elements.

3. When either phosphorus or potassium was applied alone or together the resulting annual terminal growth was less than that made by the check trees. This was especially true when only one of the two elements was applied.

4. With trees receiving nitrogen either alone or in combination with either phosphorus or potassium or both, the average diameter of the terminal growth was slightly greater than that of the check trees.

5. When phosphorus alone or potassium alone, or the two elements together were applied, the average diameter of the terminal growth tended to be slightly less than that of the check trees.

6. There was a definite correlation between the length and the diameter of the annual terminal growth, the longer the terminal growth the greater the diameter. There was, however, no definite consistent other influence of the fertilizers upon the relation of the diameter and length of the terminal growth.

7. When compared with the check trees, the annual increase in trunk circumference was somewhat greater where nitrogen was applied alone or in combination with phosphorus or potassium or both.

8. The application of phosphorus and potassium together or of phosphorus alone did not give any consistent appreciable increase in trunk circumference as compared with the check trees. The application of potassium alone seemed to result in smaller annual increases in trunk circumference as contrasted with check trees.

9. There seemed to be no appreciable direct influence upon winter killing of fruit buds from the application of the fertilizers.

10. Nitrogen alone or in combination with phosphorus or potassium resulted in an increased percentage of fruit set as compared with the unfertilized plots or the plots to which phosphorus or potassium individually or together were applied.

11. Trees in the phosphorus and the potassium plots were the lowest in per cent and in total number of fruits set. The trees receiving both phosphorus and potassium were comparable in per cent set to the check trees.

12. The fertilizers applied did not appear to influence definitely and consistently alternate bearing tendencies.

13. The number of young fruits removed at thinning time from trees receiving nitrogen alone or in combination with phosphorus or potassium or both was greater than that removed from the check trees or from trees receiving phosphorus or potassium or both.

14. The application of phosphorus and potassium together without nitrogen did not result in an increased number of thinned fruits in comparison with the check trees.

15. The application of either phosphorus alone or potassium alone has resulted in a greatly decreased number of thinned apples each year as compared with the check trees.

16. The increase in average annual production over the check trees resulting from fertilizers was in the plots of trees receiving nitrogen alone or in combination.

17. The PK plot yield was about comparable to the check; the yields of the trees of the P plot and of the K plot averaged respectively 36.2 and 24.4 per cents less than the yields of the check trees.

18. The application of nitrogen alone or in combination with either P or K has tended to somewhat increase the size of the individual fruits as compared to fruits from trees not fertilized.

19. The application of phosphorus or potassium singly or together has resulted in smaller size of individual Jonathan apples than those from trees of unfertilized plots.

20. In plots where nitrogen was applied either alone or in combination with P or K or both, the per cent of red color on the surface of the apple was less than that on apples from check trees.

21. While the average per cents of red color on apples from the P and K plots were greater than that on fruit from the check plots, the red color seemed to have been developed by the greater intensity of sunlight resulting from the marked decrease in foliage on trees so fertilized.

22. The trees in the check and PK plots produced a lower percentage of "C" grade fruit and a higher percentage of extra fancy fruit, as determined by color only, than were produced by trees in plots receiving nitrogen alone or in combination. The average number of extra fancy fruits, however, was less in the PK plots than in the check plot. The extra fancy fruits produced in the check plot were 0.2 of a box greater than produced in the N alone plot, and 0.7 of a box and 0.4 of a box less than produced in the NP and NK plots respectively. The check also produced 1.1 boxes more extra fancy fruits than the NPK plot, which was the lowest of any of the plots where N was used either alone or in combination.

23. Factors other than the fertilizers applied seemed to be more directly responsible for Jonathan breakdown except as the fertilizers affect the size, maturity, and color of fruits and the leaf-fruit ratio.

LITERATURE CITED

Alderman, W. H., and H. L. Crane. The fertilization of apple orchards. W. Va. Agr. Exp. Sta. Bul. 174. 1920.

Anderson, L. C. Some soil problems in the Hudson Valley in relation to fruit growing. New York State Hort. Soc. Proc. Ann. Meeting 75:175-182. 1930.

Anderson, L. C. Yield records of two fertilizer experiments. N. Y. State Hort. Soc. Proc. 77:106-109. 1932.

Anthony, R. D., and U. P. Hedrick. Twenty years of fertilizers in an apple orchard. N. Y. State Sta. Bul. 460:71-96. 1919.

Anthony, R. D., and J. H. Waring. Methods of interpreting yield records in apple fertilization experiments. Penn. Agr. Exp. Sta. Bul. 173. 1922.

Ballou, F. H., and I. P. Lewis. Culture and feeding of the apple orchard. Ohio Agr. Exp. Sta. Mo. Bul. 5:43-48. 1920.

Bradford, F. C. Nitrogen-carrying fertilizers and the bearing habits of mature apple trees. Mich. A.E.S. Spes. Bul. No. 127:1-32. 1924.

Brooks, W. P. Manuring an apple orchard. Mass. Agr. Exp. Sta. Bul. 922, pt 2:10-20. 1910.

Burke, E. H., H. E. Morris and F. M. Harrington. Study of apple tree growth as influenced by soil conditions in the Bitter Root Valley. Montana Agr. Exp. Sta. Bul. 241:3-23. 1931.

Chandler, W. H. Fruit Growing. Houghton-Mifflin Company, 1925.

Collison, R. C., and J. D. Harlan. Final report on the cooperative experiments in orchard fertilization. N. Y. (Geneva) A.E.S. Bul. No. 503:1-30. 1923.

Cooper J. R. A study of the effect of commercial fertilizers on the performance of apple trees. Ark. Agr. Exp. Sta. Bul. 227:1-61. 1928.

Cooper, J. R., and C. B. Wiggans. Ark. A.E.S. Bul. 268:1-52. 1931.

Dorsey, M. J., and H. E. Knowlton. Fertilization of apple orchards, II. W. Va. A.E.S. Bul. No. 203:1-53. 1926.

Fagan, F. N., R. D. Anthony, and W. S. Clarke, Jr. Twenty-five years of orchard soil fertility experiments. Penn. Agr. Exp. Sta. Bul. 294: 1-19. 1933.

Gourley, J. H. The effects of fertilizers in a cultivated orchard. N. H. A.E.S. Bul. 168:1-31. 1914.

Gourley, J. H. Sod, tillage and fertilizers for the apple orchard. N. H. A.E.S. Bul. 190:1-40. 1919.

Grubb, N. H. An analysis of the effects of potash fertilizers on apple trees at East Malling. J. Pomology Hort. Sci. 7:32-58. 1928.

Harlan, J. D., and R. C. Collison. Experiments with commercial nitrogenous fertilizers on apple orchards. N. Y. State (Geneva) Agr. Exp. Sta. Bul. 623:1-36. 1933.

Hedrick, U. P. The effect of wood ashes and acid phosphate on the yield and color of apples. N. Y. (Geneva) A.E.S. Bul. No. 289:211-235. 1907.

Hedrick, U. P. Is it necessary to fertilize an apple orchard? N. Y. (Geneva) A.E.S. Bul. No. 339:152-195. 1911.

Heinicke, A. J. Factor influencing the abscission of flowers and partially developed fruits of the apple. (*Pyrus Malus L.*) Cornell Agr. Exp. Sta. Bul. 393. 1917.

Heinicke, A. J. Composition of fruit-bud and spur tissues of Wealthy apples under different conditions of nutrition. Proc. Amer. Soc. Hort. Sci. 27:190-198. 1930.

Kocher, A. E. Soil survey of the Wenatchee area. Washington Bur. of Soils, U.S.D.A. pp. 1-91. 1918.

Larson, C. A. The effects of continued application of irrigation water and commercial fertilizers to Ephrata fine sand in the Wenatchee orchard district. Doctorate Thesis, State College of Washington, 1-78. 1931.

Larson, C. A. Effect of fertilizers on irrigated Ephrata fine sand and apple tree response in the Wenatchee orchard district. Jour. Amer. Soc. Agron. 25:633-652. 1933.

Lyon, T. L., A. J. Heinicke, and B. D. Wilson. The relation of soil moisture and nitrates to the effects of sod on apple trees. Cornell Univ. Agr. Exp. Sta. Memoir 63:1923.

Magness, J. R., F. L. Overley, and W. A. Luce. Relation of foliage to fruit size and quality in apples and pears. Wash. Agr. Exp. Sta. Bul. 249:1-26. 1931.

McCue, C. A., and F. S. Lagasse. Fertilizers for orchards. Peninsula Hort. Soc (Del.) Trans. 39:47-50. 1925.

Morris, O. M., and Roy Larson. Orchard soil management and fertilization. State College of Washington A.E.S. Bul. No. 121:1-23. 1921.

Morris, O. M. Fertilizers and cover crops on soils in the irrigated orchards of Washington. State College of Washington A.E.S. Bul. No. 217:1-37. 1927.

Overholser, E. L., and F. L Overley. Fertilizers as related to leaf area in apple production. Amer. Soc. Hort. Sci. 30:52-54. 1933.

Overley, F. L. and E. L. Overholser. Some effects of fertilizer upon storage response of Jonathan apples Proc. Am. Soc. Hort. Sci. 28:572-577. 1931.

Palmer, R. C. Recent progress in the study of Jonathan breakdown in Canada. Pub. Dom. Exp. Sta., Summerland, B. C., Oct. 6, 1930.

Shaw, J. K. Experiments in soil management and fertilization of orchards. Mass. Agr. Exp. Sta. Bul. 209. 1922.

Stewart, J. P. The fertilization of apple orchards. Penn. A.E.S. Bul. No. 153:1-31. 1918.

Tukey, H. B., and L. C. Anderson. Five years' results with fertilizers in three Hudson River Valley apple orchards. N. Y. State(Geneva) A.E.S. Bul. No. 574:1-31. 1929.